

Search For Iron, Nickel, and Fluorine in PG1159 Stars

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Abstract. A possible origin of the iron-deficiency in PG1159 stars could be neutron captures on Fe nuclei. A nickel overabundance would corroborate this idea. Consequently we are looking for nickel lines in PG1159 stars. Prime targets are relatively cool objects, because Ni VI is the dominant ionisation stage and the spectral lines of this ion are accessible with UV observations. We do not find such lines in the coolest PG1159 star observed by FUSE (PG1707+427, $T_{\text{eff}} = 85\,000$ K) and conclude that the nickel abundance is not enhanced. Hence, the Fe-deficiency in PG1159 stars remains unexplained. In addition, we present results of a wind analysis of the hybrid-PG1159 star NGC 7094 and the [WC]–PG1159 transition-type object Abell 78 in order to derive F abundances from the F VI 1139.5 Å line. In both cases, we find F overabundances, in agreement with results of photospheric analyses of many PG1159 stars. Surprisingly, we find indications for a very low O abundance in NGC 7094.

1. Search for iron and nickel in “cool” PG1159 stars

It is widely believed that PG1159 stars exhibit former AGB-star intershell matter on their surface, dredged-up by a late He-shell flash. One of the most surprising results of spectral analyses of PG1159 stars is the observed iron-deficiency in all objects investigated so far. In not a single case were Fe lines identified. The derived upper limits suggest Fe-deficiencies of the order 0.5–1.5 dex. (For a more detailed description see the PG1159 review in these proceedings by Werner et al.) One possible explanation is that Fe was transformed to heavier elements by s-process neutron captures during the preceding AGB evolution. However, AGB star evolution models do not predict such a strong Fe depletion in the intershell. Therefore, either our understanding of the s-process in AGB stars has a fundamental flaw, or the Fe-deficiency has another origin. One hint to the solution of this problem is the nickel abundance in PG1159 stars. If it is oversolar, then the hypothesis of n-captures on Fe seed nuclei would be verified. If we do not find a Ni enhancement, this hypothesis would not necessarily be disproved, because Fe might have been transformed into even heavier elements.

In contrast to the iron-abundance analysis, the nickel abundance determination in PG1159 stars is more difficult. The iron-deficiency was derived from

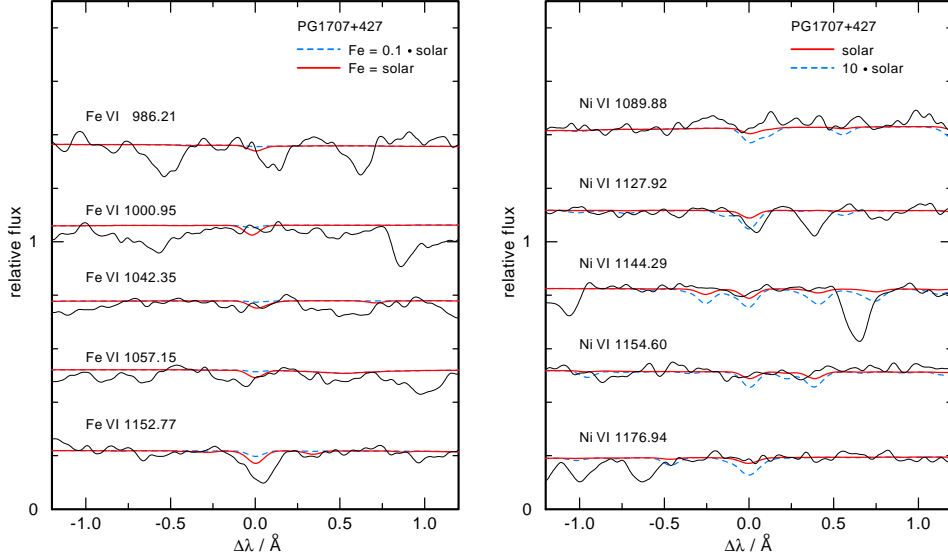


Figure 1. Sections of the FUSE spectrum of PG1707+427, centered on the strongest expected iron lines (left panel) and nickel lines (right panel). Neither species is identified. Overplotted are models with Fe and Ni abundances as given in the panels. While iron appears to be depleted, there is no simultaneous nickel enhancement. Other element abundances in the model are He/C/N/O/Ne = 0.42/0.38/0.015/0.17/0.02 (mass fractions).

the absence of Fe VII lines in UV spectra (obtained with HST and FUSE), because Fe VII is the dominant ionisation stage. From model predictions Ni VII lines should be the strongest signatures of nickel but, unfortunately, these lines are located at wavelengths below the Lyman edge and, thus, are not accessible. An alternative is offered by the coolest PG1159 stars, for which Ni VI lines are the dominant features, which are located in the FUSE spectral range. We have therefore investigated the spectrum of PG1707+427, which is the coolest PG1159 star observed by FUSE ($T_{\text{eff}} = 85\,000$ K, $\log g = 7.5$). We also analysed another relatively cool PG1159 star, PG1424+535, which is significantly hotter ($T_{\text{eff}} = 110\,000$ K, $\log g = 7.5$) and, hence, less promising for our purpose.

Our model atmospheres are plane-parallel, homogeneous non-LTE models, in hydrostatic and radiative equilibrium (Werner et al. 2003). The composition comprises the main atmospheric constituents He, C, N, O and Ne. The atmospheric parameters were taken from previous analyses (Werner & Herwig 2006). Fe and Ni were included following Rauch & Deetjen (2003) and keeping fixed the atmospheric structure.

Fig. 1 shows the comparison of PG1707+427 to models with different Fe and Ni abundances. Lines from neither species can be identified. The derived upper limit for both elements is the solar value. Nickel is certainly not oversolar, however, we cannot prove that this particular star is Fe-deficient. If it were, then the result on nickel would not corroborate the n-capture hypothesis for the Fe-deficiency. In conclusion, our results do not answer the question why PG1159 stars are generally Fe-deficient. In the case of PG1424+535, the absence of Fe VII

Table 1. Parameters of the wind models for Abell 78 and NGC 7094 (Koesterke et al. 1998). F abundances are derived in this work. ($\log F_{\odot} = -6.3$)

Object	Spectral Type	T_{eff} [kK]	$\log g$ [cm/s ²]	$\log L$ [L_{\odot}]	$\log \dot{M}$ [M_{\odot}/yr]	v_{∞} [km/s]	$\log F$ [mass fraction]
Abell 78	[WC]–PG1159	110	5.5	3.7	-7.3	3750	-5.9
NGC 7094	hybrid PG1159	110	5.7	3.6	-7.7	3500	-5.1

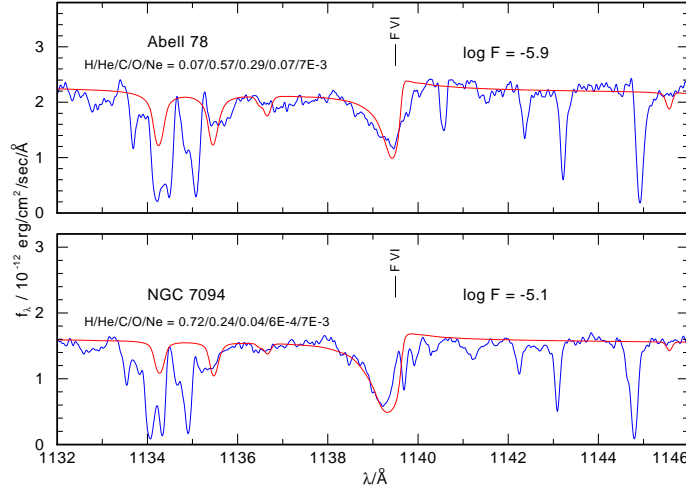


Figure 2. Details from FUSE spectra of the [WC]–PG1159 transition-type object Abell 78 (top panel) and the hybrid PG1159 star NGC 7094 (bottom) near the F VI 1139.5 Å line. Overplotted are synthetic spectra with model parameters as given in Tab. 1.

lines means an Fe-deficiency of 1 dex but, for the reasons mentioned above, no meaningful limit on the Ni abundance can be set.

2. Wind models for NGC 7094 and Abell 78

Several PG1159 objects display strong P Cygni wind profiles in their spectra, among them the central stars of Abell 78 and NGC 7094. Their parameters are summarized in Tab. 1. Based on these values we calculated expanding stellar atmosphere models using the “Hot Blast” wind code of Koesterke.

Abell 78 is a transition-type object which can be considered as a [WC] star in the phase of becoming a PG1159 star. The abundance of the main atmospheric constituents confirms this idea. The discovery that fluorine in many PG1159 stars is strongly overabundant is interesting in the context of AGB-star nucleosynthesis (Werner et al. 2005). The respective analyses were based on a newly discovered F VI line at 1139.5 Å with plane-parallel atmosphere models. The line was also discovered in Abell 78, however, the asymmetric shape sug-

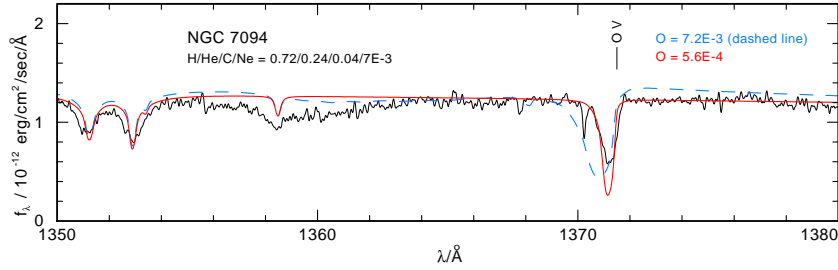


Figure 3. The O v 1371 Å line in the HST/STIS spectrum of NGC 7094. Overplotted are two models with different O abundance as depicted (mass fractions). For other model parameters see Tab. 1.

gests that the line is formed in the stellar wind. The top panel of Fig. 2 displays the FUSE spectrum together with a model fit. F is 0.4 dex oversolar.

NGC 7094 is a hybrid-PG1159 star, denoting objects in the PG1159 spectral class which have a detectable amount of residual hydrogen in their atmospheres. In contrast to the other PG1159 stars, which are the result of a late or very late thermal pulse (LTP and VLTP), hybrid-PG1159 stars are thought to be the outcome of a final TP occurring on the AGB (AFTP) immediately before the star’s departure of the AGB. Quite unexpectedly (because of residual H-envelope material which should also contain Fe in a solar Fe/H ratio), Abell 78 is strongly Fe-deficient like other PG1159 stars (see Ziegler et al. in these proceedings). NGC 7094 also shows a strong F vi 1139.5 Å line, and we derive a 1.2 dex oversolar value. Like the Fe-deficiency, the strong F enrichment is difficult to understand in the AFTP picture.

On the other hand, the low oxygen abundance in NGC 7094 as compared to other PG1159 stars corroborates the AFTP scenario. Dreizler et al. (1995) found $O \approx 0.01$ (mass fraction) from optical spectroscopy. We have computed wind models with different O abundances in order to fit the O v 1371 Å line (Fig. 3). We conclude that the O abundance is even lower than hitherto thought, by about 1 dex. This means that it is even *below* the solar value ($5.3 \cdot 10^{-3}$, Asplund et al. 2005) so that, in contrast to PG1159 stars, O is not increased by dredge-up processes from the C-O stellar core. However, this result must be regarded as preliminary, because other oxygen lines still need to be investigated.

Acknowledgments. T.R. is supported by the *German Astrophysical Virtual Observatory* (BMBF grant 05 AC6VTB), E.R. by DFG grant We1312/30–1, J.W.K. by the FUSE project, funded by NASA contract NAS5-32985.

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